REASSESSMENT OF THE RISK OF FOLIAR INJURY FROM OZONE ON VEGETATION IN PARKS EXPERIENCING INCREASES IN LEVELS OF EXPOSURE

Objective

The original assessment of the risk of foliar ozone injury on vegetation for parks in the 32 Vital Signs Networks was conducted in 2004 and used ozone exposure and soil moisture data for 1995 through 1999. This reassessment uses monitoring data for ozone from 2000 through 2004 to update the risk assessments for selected parks. Together the two assessments provide insight to the changes in ozone exposure over a ten-year period, and examine how the changes may have altered the risk of ozone injury to plants.

The reassessment of risk was conducted for Craters of the Moon National Historic Park, Death Valley National Park, Grand Canyon National Park, Great Basin National Park, Mesa Verde National Park, Rocky Mountain National Park, Sequoia and Kings Canyon National Park, and Yellowstone National Park. These parks were selected because it appeared they experienced increased levels of ozone exposure since the initial assessment. This document contains the reassessment for Sequoia and Kings Canyon National Park. Other reassessments can be accessed from the appropriate park's AQRV page on ARIS at http://www2.nature.nps.gov/air/Permits/ARIS/.

Risk Assessment Methodology

The risk assessment is based on a triad model that holds that the response of a plant to ozone is the result of the interaction of the plant, the level of exposure and the exposure environment. While interactions among the three variables determine the response, the state of any one of them can serve to accentuate or preclude the production of foliar injury. The response is greatest when all three variables and their interactions are optimized relative to the conditions that foster injury. The optimized states are: the species of plants are highly sensitive to ozone, the exposure levels of ozone significantly exceed the thresholds for foliar injury, and the environmental conditions foster gas exchange and the uptake of ozone by plants.

To conduct a risk assessment for a specific site, information was obtained on the ozone-sensitive plant species found there, the levels of ozone exposure that occur over a number of years, and, since soil moisture is a critical variable controlling gas exchange, the levels of soil moisture that exist during the periods of ozone exposure. The information was evaluated to determine the degree to which the levels of ozone exposure and soil moisture conditions integrate to create an environment that leads to the production of foliar injury on sensitive species at the site.

Ozone-Sensitive Plant Species

In 2003, a workshop was convened by the National Park Service to review the ozone research literature and apply the field experience of the attendees to develop a

comprehensive list of ozone-sensitive plant species for the eastern and western United States. Because of the emphasis of previous field studies and research, information on the ozone-sensitivity of tropical, arctic and rare species is limited. The workshop identified both sensitive and bioindicator species for ozone, and published its determinations in a National Park Service Report (U.S. National Park Service 2003). An ozone bioindicator species is one whose high level of sensitivity and characteristic pattern of foliar injury allow it to be confidently used to ascertain the occurrence of injurious levels of ozone exposure in the field. With regard to the Triad model, a bioindicator species integrates the effects of exposure and environment while optimizing plant sensitivity. A bioindicator serves as an early-warning agent for the plant community with respect to the potential impacts of ozone. Ozone-sensitive and bioindicator plant species at each site were identified by comparing the site's floral list from NPSpecies with the list of sensitive species developed at the workshop.

Levels of Ozone Exposure

Ozone exposure data for each site were obtained either from on-site monitoring or by kriging. Both monitored and kriged data have limitations. Ozone monitoring was conducted at relatively few sites, but provides the most accurate assessment of ozone exposure. However, data from a single monitor may not accurately represent exposures throughout a large park, or a park with significant elevation differences. For sites without monitoring, ozone data were statistically estimated using a technique known as kriging. This technique uses ozone data from near-by monitoring sites to estimate data for the point of interest. Most of the sites in the risk assessment have kriged data. The accuracy of the kriged data depends on the number of near-by monitoring sites, their distance and their spatial arrangement. The accuracy with which the kriged data represents the actual exposure conditions is likely to vary among the sites.

All ozone data, both monitored and kriged, were analyzed by the Air Resources Division of the National Park Service to produce annual indices of exposure for each site. Since the ozone research community has not completely accepted one index of exposure as fully characterizing the threshold for foliar injury to vegetation, the assessment employed three indices to assure a comprehensive approach was taken in the assessment.

One index is the Sum06 and its attendant thresholds for injury (Heck and Cowling 1997). This index is comprised of the 90-day maximum sum of the 0800 through 1959 hourly concentrations of ozone $\geq$ 60 ppb (0.60 ppm). The index is calculated over running 90-day periods and the maximum sum can occur over any period of the year, although the chemistry of ozone generation usually results in it occurring over the summer months. For risk assessment purposes, it is also necessary to know the three-month period over which each year's maximum index occurs.

Another index is the W126 and its associated thresholds (Lefohn et al. 1997). The W126 index is the weighted sum of the 24 one-hour ozone concentrations daily from April through October, and the number of hours of exposure to concentrations $\geq$ 100 ppb (0.10 ppm) during that period. The W126 index uses a sigmoidal weighting function in

producing the sum: the lower concentrations are given less weight than are the higher concentrations since the higher exposures play a greater role in producing injury. The significance of the higher concentrations is also reflected in the requirement that there be a specified minimum number of hours of exposure to concentrations ≥ 100 ppb. Thus, the W126 index has two criteria that must be realized to satisfy its thresholds: a minimum sum of weighted concentrations and a minimum number of hours ≥ 100 ppb.

The last indicator of ozone exposure, designated N-value, consists of the numbers of hours of exposure each year that exceeded 60, 80 and 100 ppb. While there are no formal thresholds associated with these values, they provide insight to the distribution of exposures among these concentrations, and to the numbers of hours at and above 80 and 100 ppb, levels of exposure that are associated with the production of foliar injury.

Soil Moisture Status

Although gas exchange in plants is influenced by many environmental variables, soil moisture status is a critical factor since stomatal closure during periods of low soil moisture can severely limit gas exchange. Since site-specific soil moisture data are not available for the sites, the USDA's Palmer Z Index was selected to represent soil moisture conditions. The Palmer Z Index is a measure of the short-term departure of soil moisture from the long-term mean for the area. Consequently, the index automatically takes into account the diversity in precipitation among the parks, and emphasizes the difference that exists between the monthly soil moisture norm for the site and its actual state. The index is calculated monthly for up to ten regions in each of the 48 contiguous states, and measures drought on a scale from 0.0 to –4.0, a range representing normal to severe conditions. The regions are considered to be relatively homogeneous by USDA, but contain a diversity of soil, elevation and site variables that influence the soil moisture conditions at any specific location. The Palmer Z Index is not site specific and may not fully represent the soil moisture conditions at a park during a specific month.

The objective of this aspect of the risk assessment was to determine whether there is a consistent relationship between the level of ozone exposure and soil moisture status for the site by using the five years of data available. Atmospheric conditions that foster the production of ozone, such as clear sky, high UV levels and higher temperatures, are ones associated with the presence of few clouds and reduced precipitation. Consequently, years with high levels of atmospheric ozone may also experience low levels of soil moisture. This inverse relationship can constrain the uptake of ozone by plants in years with high levels of ozone and significantly reduce the likelihood that foliar injury will be produced. Knowing whether this relationship exists at a site is essential in determining whether certain levels of ozone exposure pose a risk to vegetation.

Palmer Z data were obtained from the USDA web site and tabulated for the three-month period over which the Sum06 exposure indices were compiled, and for the May to October period associated with the W126 exposure indices. Visual analysis of the exposure and soil moisture data was undertaken to determine whether there was an association between the two factors at each site.

Site-Specific Assessment

After information on the presence of sensitive species, levels of ozone exposure and relationships between exposure and soil moisture was compiled, it was synthesized into an assessment of risk of foliar injury for the site. Risk was classified as high, medium or low. Most sites had ozone-sensitive species on them and some of species were bioindicators that could be used in field surveys for ozone injury. If a site did not have any sensitive species, the risk assessment was completed and considered to be potential until sensitive species are identified.

The Sum06 and W126 exposure indices were examined to determine whether they exceeded their respective thresholds for injury, and the frequency with which the thresholds were exceeded over the five-year assessment period. The N-value data were examined to assess the distribution of exposures in a given year, and the consistency of exposure over the five years.

Evaluation of the relationship between ozone exposure and soil moisture might indicate they are inversely related, or they are not related and months of drought occur independent of the level of ozone exposure. At a site where exposure and drought are inversely related, the uptake of ozone is constrained by drought stress in the highest exposure years. In this instance, the risk of foliar ozone injury is likely greatest in years with lower levels of exposure that still exceed the injury thresholds and with soil moisture conditions that are more favorable for the uptake of ozone. In these cases, the greatest risk of foliar injury does not necessarily occur in the year with the highest level of ozone exposure. At sites where exposure and soil moisture are not related, the risk of foliar injury in a given year is a function of the random co-occurrence of high exposure and favorable moisture conditions.

The risk of foliar ozone injury at a site was determined by analyzing the plant, exposure and moisture data. The process was not quantitative, but based upon three primary evaluations: the extent and consistency by which the ozone injury thresholds were exceeded by the Sum06 and W126 exposure indices, the nature of the relationship between exposure and soil moisture, and the extent to which soil moisture conditions constrained the uptake of ozone in high exposure years. The evaluation of these factors and the assessment of their interactions with ozone-sensitive plant species is consistent with the triad model of risk assessment, and comprises the framework for determining whether the risk of foliar ozone injury was high, moderate or low at each site. The accuracy of a site's risk assessment is dependent upon the quality of the plant list, the accuracy of the ozone exposure data and the degree to which the regional soil moisture data represent conditions at the site.

Sites receiving a risk rating of high have a probability of experiencing foliar injury in most years, while those rated low are not likely to experience injury in any year. A rating of moderate was assigned to sites where analysis indicated injury was likely to occur at some point in the five-year period, but the chance of injury occurring consistently was low. In other words, foliar injury will probably occur at sites rated moderate, but it is not

anticipated it will occur regularly or frequently. Sites rated moderate are likely to experience a wide temporal variation in the occurrence of injury, and over a period of time may experience injury for one or more years while also experiencing several years without injury.

Literature Cited

Heck, W.W. and E.B. Cowling. 1997. The Need for a Long-term Cumulative Secondary Ozone Standard - An Ecological Perspective. Environmental Management. January

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SEQUOIA & KINGS CANYON NATIONAL PARK (SEKI)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Artemisia douglasiana	Mugwort	Asteraceae
Physocarpus capitatus	Ninebark	Rosaceae
Pinus jeffreyi	Jeffrey pine	Pinaceae
Pinus ponderosa	Ponderosa pine	Pinaceae
Populus tremuloides	Quaking aspen	Salicaceae
Rhus trilobata	Skunkbush	Anacardiaceae
Salix scouleriana	Scouler's willow	Saliaceae
Sambucus mexicana	Blue elderberry	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone monitored on-site were analyzed to generate annual exposure values. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100,

respectively).

Ozone air quality data for SEKI					
	1995	1996	1997	1998	1999
Sum06	-	-	74	66	77
W126	-	-	107.8	75.2	29.8
N60	-	-	1792	1221	2187
N80	-	-	589	400	851
N100	-	-	72	62	164

Ozone air quality data for SEKI					
	2000	2001	2002	2003	2004
Sum06	51	67	86	71	39
W126	66.7	116.3	163.3	106.7	92.3
N60	1233	2106	2619	1775	1739
N80	198	508	989	571	346
N100	6	26	168	83	17

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at SEKI					
	1995	1996	1997	1998	1999
Month 1	3.44	1.54	-2.14	5.60	0.84
Month 2	1.55	0.65	-1.72	1.98	0.32
Month 3	-0.88	-0.54	-0.84	1.03	-0.66

Palmer Z Index data for 3-month Sum06 period at SEKI					
	2000	2001	2002	2003	2004
Month 1	0.86	-1.40	-0.25	-0.25	-1.79
Month 2	-0.40	-0.97	-0.79	-0.79	-0.98
Month 3	0.01	-0.74	-0.71	-0.71	-0.89

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at SEKI					
	1995	1996	1997	1998	1999
April	1.09	-0.07	-2.47	1.62	0.17
May	3.82	2.50	-2.98	6.71	-0.31
June	3.64	1.54	-2.14	4.64	0.97
July	3.44	0.65	-1.72	5.60	0.84
August	1.55	-0.54	-0.84	1.98	0.32
September	-0.88	-1.07	-0.73	1.03	-0.66
October	-2.12	1.68	-0.70	-0.55	-1.96

Palmer Z Index data for the 7-month W126 period at SEKI					
	2000	2001	2002	2003	2004
April	-0.48	1.35	-1.44	3.06	2.54
May	0.89	-1.32	0.46	1.73	-2.15
June	0.86	-1.40	-0.25	1.17	-2.28
July	-0.40	-0.97	-0.79	0.42	-1.79
August	0.01	-0.74	-0.71	0.76	-0.98
September	-0.15	-0.87	-1.12	-1.17	-0.89
October	3.62	-1.09	-1.75	-2.41	6.09

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.

1995-1999

- Only three years of ozone monitoring data are available for assessing the Sum06 and W126 indices of exposure. The Sum06 index significantly exceeds the threshold for foliar injury. The W126 accumulative value and the N100 count are significantly greater than their threshold values, thus the criteria for injury under the W126 index are satisfied. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.

- In the three years of monitoring data, the N-values for concentrations of 60, 80, and 100 ppb are all elevated and show there are a significant number of hours during which plants are exposed to levels of ozone likely to produce foliar injury.

- Since only three years of ozone monitoring data are available, statements regarding the relationship between ozone exposure and soil moisture are speculative and subject to assessment of additional data. The 90-day Sum06 accumulative indices of exposure were relatively similar across the three years, and no association is apparent between exposure level and soil moisture. Two months of mild and moderate drought occurred in the second highest ozone year, 1997, and soil moisture was favorable in the other two years. The seasonal W126 exposure indices varied greatly among the three years, and it appears there may be an inverse relationship between ozone exposure and soil moisture: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the seasonal exposure in producing foliar injury. In the highest ozone year, 1997, there were four months of mild and moderate drought. Ozone exposure was considerably lower in the other two years and there was only one month of mild drought between them. Conclusions for both the Sum06 and W126 exposures are subject to further confirmation.

2000-2004

- The Sum06 index significantly exceeds the threshold for foliar injury. The W126 accumulative value significantly exceeds its threshold and the N100 count is significantly greater than the required minimum value in most years, thus the criteria for injury under the W126 index are satisfied. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.

- The N-values for concentrations of 60, 80, and 100 ppb are all elevated and show there are a significant number of hours during which plants are exposed to levels of ozone likely to produce foliar injury.

- Soil moisture levels during the 90-day Sum06 accumulation periods show minimum water stress and thus ozone uptake would be fostered. Only two years, 2001 and 2004, had one month of mild drought each. Soil moisture levels associated with seasonal W126 index of exposure appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. The two highest years of exposure, 2002 and 2001, had three and four months of mild drought, respectively, while the second lowest year, 2004, had three months of mild and moderate drought and soil moisture was normal in the lowest year, 2000.

The risk of foliar ozone injury to plants at Sequoia and Kings Canyon National Park is high. The levels of ozone exposure consistently create the potential for injury in both the Sum06 and W126 indices over the eight years of data available. The apparent inverse relationship between ozone exposure and soil moisture constrains the uptake of ozone at higher exposures and reduces the likelihood that the exposures will produce foliar injury. However, levels of exposure are high most years and the probability of foliar injury developing may be greatest during years such as 1998, 1999, and 2000 when ozone levels exceed thresholds, and soil moisture levels do not place constrains on the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, mugwort, ninebark, ponderosa pine, quaking aspen, skunkbush, Scouler's willow, and blue elderberry.